

WHAT IS CLAIMED IS:

1 1. A hearing aid, comprising:
2 an input signal channel providing digital input signals;
3 a signal path adapted to process said digital input signals in accordance
4 with a predetermined signal processing algorithm to produce a digital output signal,
5 wherein said signal path further comprises at least one signal processing function
6 operating on a warped frequency scale, and wherein said at least one signal processing
7 function includes at least one spectral enhancement algorithm; and
8 an output conversion means adapted to convert said output signals to an
9 audio output.

1 2. The hearing aid of claim 1, wherein said at least one signal
2 processing function further comprises a plurality of cascaded all-pass filters.

1 3. The hearing aid of claim 1, wherein said warped frequency scale
2 approximates a Bark scale.

1 4. A frequency-warped processing system, comprising:
2 an input signal channel providing digital input signals;
3 a plurality of cascaded all-pass filters, wherein said digital input signals
4 pass through said plurality of cascaded all-pass filters, and wherein said plurality of
5 cascaded all-pass filters output a sequence of delayed samples;
6 means for applying a frequency domain transform on said sequence of
7 delayed samples, wherein a warped sequence results from said frequency domain
8 transform applying means;
9 means for calculating a plurality of frequency domain level estimates from
10 said warped sequence;
11 means for calculating a plurality of frequency domain gain coefficients
12 from said plurality of frequency domain level estimates;
13 means for calculating a plurality of spectral enhancement gain coefficients
14 from said warped sequence;

15 means for calculating a plurality of compression-spectral enhancement
16 gain coefficients from said plurality of frequency domain gain coefficients and said
17 plurality of spectral enhancement gain coefficients;
18 means for applying an inverse frequency domain transform on said
19 plurality of compression-spectral enhancement gain coefficients, wherein a set of time-
20 domain filter coefficients of a compression gain filter result from said inverse frequency
21 domain transform applying means; and
22 means for convolving said sequence of delayed samples with said set of
23 time-domain filter coefficients to produce a digital output signal.

1 5. The frequency-warped processing system of claim 4, said means
2 for calculating said plurality of spectral enhancement gain coefficients further comprising
3 a spectral enhancement algorithm, wherein said spectral enhancement algorithm raises a
4 power spectrum comprised of said plurality of frequency domain level estimates to a
5 power greater than 1.

1 6. The frequency-warped processing system of claim 4, said means
2 for calculating said plurality of spectral enhancement gain coefficients further comprising
3 a spectral enhancement algorithm, wherein said spectral enhancement algorithm amplifies
4 a plurality of peaks of said warped sequence.

1 7. The frequency-warped processing system of claim 6, wherein said
2 spectral enhancement algorithm further comprises means for identifying said plurality of
3 peaks, said identifying means including means for applying a second-difference operator
4 to said warped sequence.

1 8. The frequency-warped processing system of claim 4, said means
2 for calculating said plurality of spectral enhancement gain coefficients further comprising
3 a spectral enhancement algorithm, wherein said spectral enhancement algorithm includes
4 means for forming an unsmeared warped sequence, and means for calculating the
5 difference between said warped sequence and said unsmeared warped sequence.

1 9. The frequency-warped processing system of claim 4, further
2 comprising a hearing aid, wherein the frequency-warped processing system is
3 incorporated within said hearing aid.

1 10. The frequency-warped processing system of claim 4, wherein said
2 plurality of frequency domain gain coefficients comprise a warped time-domain filter.

1 11. The frequency-warped processing system of claim 4, further
2 comprising means for windowing said sequence of delayed samples, wherein a windowed
3 sequence of delayed samples results from said windowing means, and wherein said
4 warped sequence results from applying said frequency domain transform to said
5 windowed sequence of delayed samples.

1 12. The frequency-warped processing system of claim 4, further
2 comprising a digital-to-analog converter, said digital-to-analog converter converting said
3 digital output signals to analog output signals.

1 13. The frequency-warped processing system of claim 12, further
2 comprising an output transducer, said output transducer converting said analog output
3 signals to an audio output.

1 14. The frequency-warped processing system of claim 4, said plurality
2 of cascaded all-pass filters comprising a plurality of first order all-pass filters.

1 15. The frequency-warped processing system of claim 4, said sequence
2 of delayed samples comprising 16 samples.

1 16. The frequency-warped processing system of claim 4, further
2 comprising a digital processor, wherein said digital processor is adapted to provide said
3 frequency domain transform applying means, said frequency domain level estimates
4 calculating means, said frequency domain gain coefficients calculating means, said
5 spectral enhancement gain coefficients calculating means, said inverse frequency domain
6 transform applying means, and said means for convolving said sequence of delayed
7 samples.

1 17. The frequency-warped processing system of claim 16, wherein said
2 digital processor comprises a software programmable digital signal processor.

1 18. The frequency-warped processing system of claim 4, wherein said
2 frequency domain transform applying means uses a transform selected from the group

3 consisting of discrete Fourier transforms, fast Fourier transforms, Goertzel transforms,
4 and discrete cosine transforms.

1 19. The frequency-warped processing system of claim 4, further
2 comprising:
3 an input transducer, said input transducer converting audio input signals to
4 analog input signals; and
5 an analog-to-digital converter, said analog-to-digital converter converting
6 said analog input signals to said digital input signals.

1 20. The frequency-warped processing system of claim 4, further
2 comprising:
3 a digital-to-analog converter, said digital-to-analog converter converting
4 said digital output signals to analog output signals; and
5 an output transducer, said output transducer converting said analog output
6 signals to an audio output.

1 21. A frequency-warped processing system, comprising:
2 an input signal channel providing digital input signals;
3 an input data buffer, said input data buffer holding at least one block of
4 data comprised of a portion of said digital input signals;
5 a plurality of cascaded all-pass filters, wherein a first block of said digital
6 input signals pass from said input data buffer through said plurality of cascaded all-pass
7 filters, and wherein said plurality of cascaded all-pass filters output a first sequence of
8 delayed samples;
9 means for windowing a first portion of said first sequence of delayed
10 samples, wherein a first windowed sequence of delayed samples results from said
11 windowing means;
12 means for applying a first frequency domain transform on said first
13 windowed sequence of delayed samples, wherein a first warped sequence results from
14 said first frequency domain transform applying means;
15 means for calculating a first plurality of frequency domain level estimates
16 of said first warped sequence;
17 means for calculating a first plurality of spectral enhancement gain
18 coefficients from said first warped sequence;

means for windowing a second portion of said first sequence of delayed
 samples, wherein a second windowed sequence of delayed samples results from said
 windowing means;
 means for applying a second frequency domain transform on said second
 windowed sequence of delayed samples, wherein a second warped sequence results from
 said second frequency domain transform applying means;
 means for calculating a second plurality of frequency domain level
 estimates of said second warped sequence;
 means for calculating a first plurality of spectral enhancement gain
 coefficients from said first warped sequence;
 means for summing said first and second plurality of spectral enhancement
 gain coefficients, wherein a summed first and second plurality of spectral enhancement
 gain coefficients results from said summing means;
 means for summing said first and second plurality of frequency domain
 level estimates, wherein a summed first and second plurality of frequency domain level
 estimates results from said summing means;
 means for normalizing said summed first and second plurality of frequency
 domain level estimates, wherein a normalized first and second plurality of frequency
 domain level estimates results from said normalizing means;
 means for calculating a plurality of frequency domain gain coefficients
 from said normalized first and second plurality of frequency domain level estimates;
 means for calculating a plurality of compression-spectral enhancement
 gain coefficients from said plurality of frequency domain gain coefficients and said
 summed first and second plurality of spectral enhancement gain coefficients;
 means for applying an inverse frequency domain transform on said
 plurality of compression-spectral enhancement gain coefficients, wherein a set of time-
 domain filter coefficients of a compression gain filter result from said inverse frequency
 domain transform applying means; and
 means for convolving a second sequence of delayed samples with said
 time-domain filter coefficients, said second sequence of delayed samples produced by a
 second block of said digital input signals passing from said input data buffer through said
 plurality of cascaded all-pass filters, wherein a digital output signal results from said
 convolving means.

1 22. The frequency-warped processing system of claim 21, said means
2 for calculating said first and second plurality of spectral enhancement gain coefficients
3 further comprising a spectral enhancement algorithm, wherein said spectral enhancement
4 algorithm raises a power spectrum comprised of said plurality of frequency domain level
5 estimates to a power greater than 1.

1 23. The frequency-warped processing system of claim 21, said means
2 for calculating said first and second plurality of spectral enhancement gain coefficients
3 further comprising a spectral enhancement algorithm, wherein said spectral enhancement
4 algorithm amplifies a plurality of peaks of said warped sequence.

1 24. The frequency-warped processing system of claim 23, wherein said
2 spectral enhancement algorithm further comprises means for identifying said plurality of
3 peaks, said identifying means including means for applying a second-difference operator
4 to said warped sequence.

1 25. The frequency-warped processing system of claim 21, said means
2 for calculating said first and second plurality of spectral enhancement gain coefficients
3 further comprising a spectral enhancement algorithm, wherein said spectral enhancement
4 algorithm includes means for forming an unsmeared warped sequence, and means for
5 calculating the difference between said warped sequence and said unsmeared warped
6 sequence.

1 26. The frequency-warped processing system of claim 21, further
2 comprising a hearing aid, wherein the frequency-warped processing system is
3 incorporated within said hearing aid.

1 27. The frequency-warped processing system of claim 21, wherein said
2 plurality of frequency domain gain coefficients comprise a warped time-domain filter.

1 28. The frequency-warped processing system of claim 21, further
2 comprising a digital-to-analog converter, said digital-to-analog converter converting said
3 digital output signals to analog output signals.

1 29. The frequency-warped processing system of claim 28, further
2 comprising an output transducer, said output transducer converting said analog output
3 signals to an audio output.

1 30. The frequency-warped processing system of claim 21, said
2 plurality of cascaded all-pass filters comprising a plurality of first order all-pass filters.

1 31. The frequency-warped processing system of claim 21, further
2 comprising a digital processor, wherein said digital processor is adapted to provide said
3 windowing means, said means for applying said first and second frequency domain
4 transforms, said means for calculating said first and second plurality of frequency domain
5 level estimates, said summing means, said normalizing means, said frequency domain
6 gain coefficients calculating means, said inverse frequency domain transform applying
7 means, and said convolving means.

1 32. The frequency-warped processing system of claim 21, wherein said
2 means for applying said first and second frequency domain transforms use a transform
3 selected from the group consisting of discrete Fourier transforms, fast Fourier transforms,
4 Goertzel transforms, and discrete cosine transforms.

1 33. The frequency-warped processing system of claim 21, further
2 comprising:
3 an input transducer, said input transducer converting audio input signals to
4 analog input signals; and
5 an analog-to-digital converter, said analog-to-digital converter converting
6 said analog input signals to said digital input signals.

1 34. The frequency-warped processing system of claim 21, further
2 comprising:
3 a digital-to-analog converter, said digital-to-analog converter converting
4 said digital output signals to analog output signals; and
5 an output transducer, said output transducer converting said analog output
6 signals to an audio output.

35. The frequency-warped processing system of claim 21, wherein said windowing means provides a 50 percent overlap of said first and second pluralities of frequency domain level estimates.

36. The frequency-warped processing system of claim 21, wherein a quantity of samples corresponding to said first block of said digital input signals is equivalent to a quantity of first order all-pass filters corresponding to said plurality of cascaded all-pass filters.

37. The frequency-warped processing system of claim 36, wherein said first portion of said first sequence of delayed samples is comprised of a first half of said first sequence of delayed samples and said second portion of said first sequence of delayed samples is comprised of a second half of said first sequence of delayed samples.

38. A frequency-warped processing system, comprising:
an input signal channel providing digital input signals;
an input data buffer, said input data buffer holding a block of data of size M comprised of a portion of said digital input signals;
a plurality of cascaded all-pass filters comprised of 2M cascaded all-pass filters, wherein a first block of said digital input signals pass from said input data buffer through said plurality of cascaded all-pass filters to form a first sequence of delayed samples and wherein a second block of said digital input signals pass from said input data buffer through said plurality of cascaded all-pass filters to form a second sequence of delayed samples, and wherein said first sequence of delayed samples and said second sequence of delayed samples form a combined sequence of delayed samples;
means for windowing a first portion of said combined sequence of delayed samples, wherein said first portion is of size M, wherein a windowed sequence of delayed samples results from said windowing means;
means for applying a 2M-point frequency domain transform on said windowed sequence of delayed samples, wherein a warped sequence results from said frequency domain transform applying means;
means for calculating a plurality of frequency domain level estimates of said warped sequence;

means for calculating a plurality of frequency domain gain coefficients
from said plurality of frequency domain level estimates;
means for calculating a plurality of spectral enhancement gain coefficients
from said warped sequence;
means for calculating a plurality of compression-spectral enhancement
gain coefficients from said plurality of frequency domain gain coefficients and said
plurality of spectral enhancement gain coefficients;
means for applying an inverse frequency domain transform on said
plurality of compression-spectral enhancement gain coefficients, wherein a set of time-
domain filter coefficients of a compression gain filter result from said inverse frequency
domain transform applying means; and
means for convolving a second portion of said combined sequence of
delayed samples with said set of time-domain filter coefficients, wherein said second
portion is of size M, wherein a digital output signal results from said convolving means.

39. The frequency-warped processing system of claim 38, said means
for calculating said plurality of spectral enhancement gain coefficients further comprising
a spectral enhancement algorithm, wherein said spectral enhancement algorithm raises a
power spectrum comprised of said plurality of frequency domain level estimates to a
power greater than 1.

40. The frequency-warped processing system of claim 38, said means
for calculating said plurality of spectral enhancement gain coefficients further comprising
a spectral enhancement algorithm, wherein said spectral enhancement algorithm amplifies
a plurality of peaks of said warped sequence.

41. The frequency-warped processing system of claim 40, wherein said
spectral enhancement algorithm further comprises means for identifying said plurality of
peaks, said identifying means including means for applying a second-difference operator
to said warped sequence.

42. The frequency-warped processing system of claim 38, said means
for calculating said plurality of spectral enhancement gain coefficients further comprising
a spectral enhancement algorithm, wherein said spectral enhancement algorithm includes

4 means for forming an unsmeared warped sequence, and means for calculating the
5 difference between said warped sequence and said unsmeared warped sequence.

1 43. The frequency-warped processing system of claim 38, further
2 comprising a hearing aid, wherein the frequency-warped processing system is
3 incorporated within said hearing aid.

1 44. The frequency-warped processing system of claim 38, wherein said
2 plurality of frequency domain gain coefficients comprise a warped time-domain filter.

1 45. The frequency-warped processing system of claim 38, further
2 comprising a digital-to-analog converter, said digital-to-analog converter converting said
3 digital output signals to analog output signals.

1 46. The frequency-warped processing system of claim 45, further
2 comprising an output transducer, said output transducer converting said analog output
3 signals to an audio output.

1 47. The frequency-warped processing system of claim 38, said
2 plurality of cascaded all-pass filters comprising a plurality of first order all-pass filters.

1 48. The frequency-warped processing system of claim 38, further
2 comprising a digital processor, wherein said digital processor is adapted to provide said
3 windowing means, said means for applying said 2M-point frequency domain transform,
4 said means for calculating said plurality of frequency domain level estimates, said
5 frequency domain gain coefficients calculating means, said inverse frequency domain
6 transform applying means, and said convolving means.

1 49. The frequency-warped processing system of claim 38, wherein said
2 means for applying said frequency domain transform uses a transform selected from the
3 group consisting of discrete Fourier transforms, fast Fourier transforms, Goertzel
4 transforms, and discrete cosine transforms.

1 50. The frequency-warped processing system of claim 38, further
2 comprising:
3 an input transducer, said input transducer converting audio input signals to
4 analog input signals; and

5 an analog-to-digital converter, said analog-to-digital converter converting
6 said analog input signals to said digital input signals.

1 51. The frequency-warped processing system of claim 38, further
2 comprising:
3 a digital-to-analog converter, said digital-to-analog converter converting
4 said digital output signals to analog output signals; and
5 an output transducer, said output transducer converting said analog output
6 signals to an audio output.

1 52. A signal processing system, comprising:
2 an input signal channel providing digital input signals;
3 means for calculating a power spectrum for said digital input signals;
4 means for applying a second difference operator to said power spectrum to
5 locate a plurality of power spectrum peaks;
6 means for amplifying said plurality of power spectrum peaks to achieve a
7 modified power spectrum; and
8 means for producing a digital output signal from said modified power
9 spectrum.

1 53. The signal processing system of claim 52, further comprising
2 means for determining the sharpness of each of said plurality of power spectrum peaks.

1 54. The signal processing system of claim 53, wherein said amplifying
2 means applies a scaling factor to the amplification applied to each of said plurality of
3 power spectrum peaks, said scaling factor based on the determined sharpness of the peak.

1 55. A method of processing sound in a hearing aid, comprising the
2 steps of:
3 receiving digital input signals;
4 passing a portion of said digital input signals through a plurality of
5 cascaded all-pass filters to form a sequence of delayed samples;
6 windowing said sequence of delayed samples;
7 applying a frequency domain transform to said windowed sequence of
8 delayed samples to form a warped sequence;

9 calculating a plurality of frequency domain level estimates from said
10 warped sequence;
11 calculating a plurality of frequency domain gain coefficients from said
12 plurality of frequency domain level estimates to form a warped time-domain filter;
13 calculating a plurality of spectral enhancement gain coefficients from said
14 warped sequence;
15 calculating a plurality of compression-spectral enhancement gain
16 coefficients from said plurality of frequency domain gain coefficients and said plurality of
17 spectral enhancement gain coefficients;
18 applying an inverse frequency domain transform on said plurality of
19 compression-spectral enhancement gain coefficients to form a set of time-domain filter
20 coefficients; and
21 convolving said sequence of delayed samples with said set of time-domain
22 filter coefficients to produce a digital output signal.